ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA42

COMPACT S-BAND ACCELERATING STRUCTURE FOR MEDICAL APPLICATIONS

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Abstract

This paper describes electromagnetic design results for the compact 6.3 MeV electron linac for the radiation therapy facility. Linac is based on S-band biperiodic accelerating structure with inner coupling cells with an increased coupling coefficient.

INTRODUCTION

Biperiodic accelerating structures with on-axis coupling cells with high cell-to-cell coupling coefficients have been developed in NRNU MEPhI since 2010 [1-5]. The joint team of CORAD and MEPhI has constructed a linear electron accelerator for industrial applications based on the developed structures [6, 7]. That accelerator was successfully launched, tested and put into operation in 2015 [8]. Linac has high electrical efficiency, narrow beam energy spectrum, provides energy regulation, and low accelerated beam losses. It is based on 2856 MHz biperiodic accelerating structure for the energy range from 7.5 to 10 MeV and beam power up to 20 kW. The klystron TH2173F (Thales Electron Devices) was used for linac RF feed. It provides up to 5 MW of pulse power for 17 μs RF pulses duration and up to γ 6 kW of averaged power. Another two accelerators have been manufactured, installed at EB-Tech Company site in Daejeon, Republic of Korea, and at "Rodniki" Industrial Park, Ivanovo Region, Russia, and successfully tested [8].

This paper presents biperiodic accelerating structure with inner coupling cells with an increased coupling coefficient. It was developed for compact 6.3 MeV electron linac for radiation therapy facility. The power source that is planned to use is 3 MW magnetron MI456B or E2Vmg7095. The operating frequency of these sources are 2997.8 MHz. Since the accelerating structures should be tuned to the source frequency, the operating frequency of the linac should be set at 2997.8±1.0 MHz.

The structure was based on the MEPhI and CORAD designed S-band linac operated at 2856 MHz design with relatively large cell-to-cell coupling coefficient [3]. Structures operating at frequency of 2856 MHz have one more advantage: the production technology was earlier developed and is ready [8]. However, the 2856 MHz structures cannot be used in the facility under development due to the fact that operating frequency does not correspond to power source one. For this reason, the accelerating structure geometry was scaled in order to reach the 2997.8 MHz RF frequency, while keeping the coupling coefficient of at least 8% and reach the highest possible shunt impedance.

The optimization of the structure in order to increase the shunt impedance is necessary because of power source limitations and necessary beam parameters to be met.

Accelerating section of this linac has been designed under the strict limitations on the facility length and ratio of electromagnetic fields values in bunching cells. Linac technical requirements are summarized below in the Table 1.

The geometry of the structure is developed according to the beam dynamics simulation results and the electrodynamic parameters requirements. The longitudinal dimensions were calculated from beam dynamics. The angle and depth of the drift tube cones and the diaphragm thickness were selected on the basis of the original structure and were kept unchanged due to the fact that the overvoltage factor value in the base structure was low enough for fast conditioning and stable operation.

Table 1: Technical Requirements for Accelerating Structures of the Compact 6.3 MeV Electron Linac for Radiation Therapy Facility

Parameter	**Value**	**Unit**
Total length	400<	mm
Number of bunching cells	3	
Number of regular cells	5	
Operating frequency	2997.8	MHz
Coupling coefficient	8…10	%
Shunt impedance	65…90	MΩ/m
Total Loss	1.6<	MW
Ratio of EM field values in buncher	0.4…1	
RF Power source	3	MW

REGULAR CELLS

Dimensions of regular cells were adjusted by scaling [5] the original structure [3] in order to achieve the required values of the cell operating frequency, shunt impedance and the coupling coefficient. Then the particular dimensions were adjusted to make the result more precise. Fine tune was done using electromagnetic field simulation software CST Studio Suite [9]. The cell tuning was considered successful when the value of the accelerating field in the coupling cells turned out to be zero upon reaching the above parameters.

The coupling coefficient and the shunt impedance values were adjusted using the position and the area of the coupling slots. The obtained electrodynamic characteristics are presented in Table 2.

The geometry of the regular cell, electric field topography and the accelerating field distribution along the tuned cavity axis for 1 J of stored energy respectively are presented on the Fig. 1.

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Table 2: RF Parameters of the Regular Cavity

Parameter	**Value**	**Unit**
Operating frequency	2997.8	MHz
Coupling coefficient	8.1	%
Q-factor	15200	
Effective Shunt Impedance	79,05	MΩ/m
Overvoltage factor	2.28	

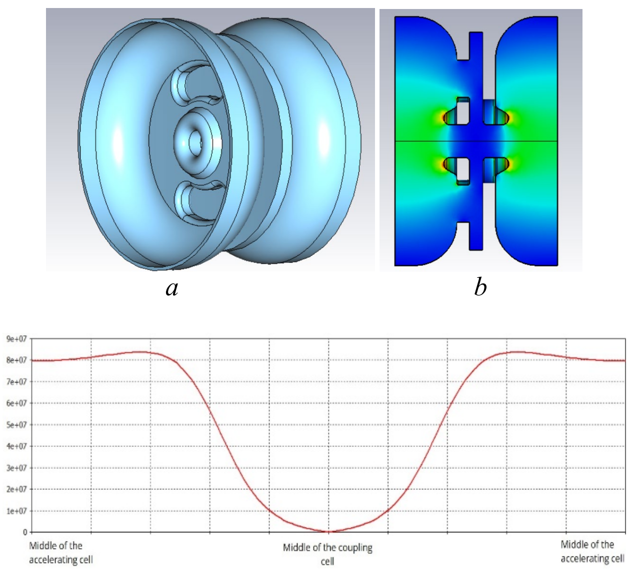

Figure 1: Geometry of the regular cell (*a*); Electric field topography (*b*); The distribution of the longitudinal component of the electric field on the cell axis for 1 J of stored energy (*c*).

BUNCHING CELLS

According to the requirements of the beam dynamics calculation accelerating structure includes 3 bunching cells. Ratio of electromagnetic fields values are in the range of 0.4 to 1 from the beginning of the bunching part. The electromagnetic fields ratio can be set up by changing the ratio between areas of the coupling gaps of the buncher. For this reason, it is necessary to take into account the margin in the area of the coupling slots in order to establish the required ratio of the accelerating fields in the buncher when designing the regular part.

An attempt was made to increase the area of coupling slots in order to get the coupling coefficient as high as 10%. However, the creation of a buncher without depriving the first two cells of noses was not possible. The deprivation of two buncher cells of noses would lead to a noticeable deterioration in the shunt impedance of the structure, below the minimum possible value. Therefore, it was decided to create a compromise option with a coupling coefficient of 8% and an acceptable shunt impedance.

The first bunching cell was designed without a nose in order to achieve the necessary electromagnetic field distribution. The sectional side view of the bunching part is presented on the Fig. 2.

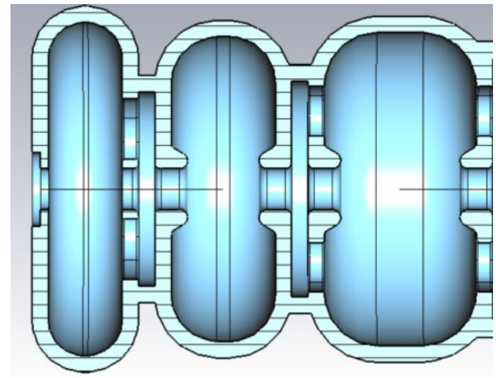

Figure 2: Sectional side view of the bunching part.

THE WHOLE STRUCTURE

According to the requirements of the beam dynamics calculation the accelerating structure consists of 3 bunching and 5 regular cells. The geometry of the whole structure is presented on the Fig. 3.

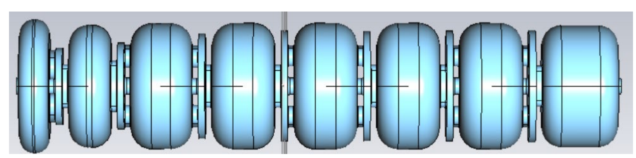

Figure 3: Side view of the S-band accelerating structure.

The electric field topography and the distribution of the module of the longitudinal component of the electric field on the axis of the tuned structure for 1 J of stored energy respectively are presented on the Fig. 4.

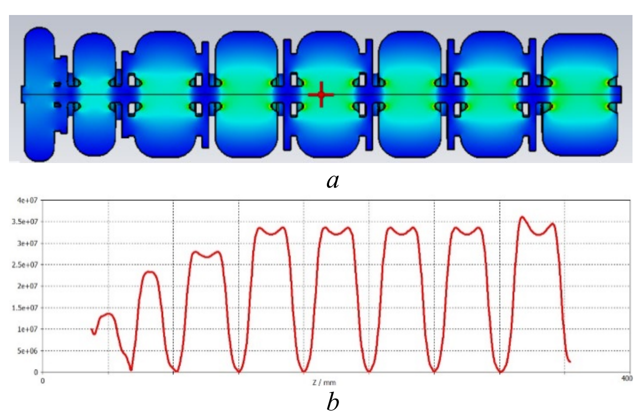

Figure 4: Electric field topography (*a*) and the distribution of the module of the longitudinal component of the electric field on the axis of the tuned structure for 1 J of stored energy (*b*).

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The first and last cells of the structure have coupling gaps only on the one side. For this reason, they were additionally tuned to achieve the symmetric electric field distribution.

To obtain the precise operating frequency for the whole linac structure, the radius of each cell was individually slightly modified after all preliminary tuned cells of the structure were put together.

The electrodynamic characteristics of the structure are presented in Table 3. The obtained cell-to-cell coupling coefficient value is relatively large at the optimal shunt impedance value for the power supply system.

Table 3: Electrodynamic Characteristics of an Optimized S-Band Accelerating Structure

Parameter	Value	Unit
Operating frequency	2997.8	MHz
Q-factor	15300	
Effective Shunt Impedance	68,89	MΩ/m
Overvoltage factor	2.64	

THE INPUT COUPLER

The accelerating structure is fed with RF power through power coupler of traditional design. Feeding WG10 (72*34mm) rectangular waveguide is coupled to accelerating cell via rectangular coupling slot.

Overcoupling factor of about 2.4 without beam loading provides near to critical coupling at specified beam current. Electromagnetic field in coupler cell is symmetrised by additional cut-off waveguide used also as vacuum pumping port. Accelerating structure with the power coupler is presented on the Fig. 5.

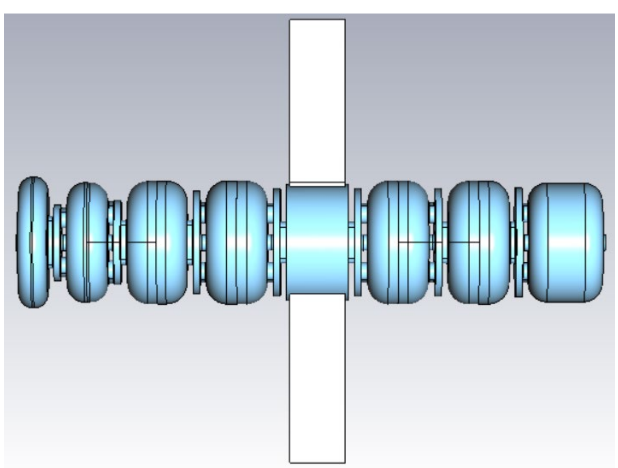

Figure 5: Side view of the S-band accelerating structure with the power coupler.

CONCLUSION

A 2997.8 MHz biperiodic accelerating structure for the compact 6.3 MeV electron linac for the radiation therapy facility was successfully designed. The final optimized geometry of the e-linac structure is presented in Fig. 3 and its electrodynamic characteristics are summarized in Table 3. The structure was optimized to produce a symmetric electric field with a ratio of electromagnetic fields values in the range of 0.4 to 1 in the bunching part as shown in Fig. 4.

The position of the power input device was selected, taking into account the infrastructure of the project. The optimal value of the coupling coefficient has been calculated.

The electron gun for the radiation therapy complex project is also in the design process.

REFERENCES

[1] N.P. Sobenin *et al.*, “Biperiodic accelerating structure with inner coupling cells with an increased coupling coefficient”, in *Proc. XXIII Russian Particle Accelerator Conference (RuPAC 2012),* Peterhof, St. Petersburg, Russia, 24 - 28 September 2012, pp 458 – 460.

[2] R.A. Kostin *et al.*, “Thermal Calculation of Accelerating Structures in Electron Linacs”, *Technical Physics*, Vol. 58, No. 4, pp. 601–607, 2013. doi:10.1134/S1063784213040105

[3] E.A. Savin and N.P. Sobenin, “Biperiodic accelerating structure with internal coupling cells with an increased coupling coefficient”, *Technical Physics*, volume 83, issue. 5, p 12, 2013. doi: 10.1134/S1063784213050198

[4] S.M. Polozov and A.I. Pronikov, “Influence of the Frequency Detuning to Electrodynamics Parameters of an Electron Linac”, *Journal of Physics: Conference Series*, 1238:012076, 2019. doi: 10.1088/1742-6596/1238/1/012076

[5] R. Zbruev *et al*., "Analysis of restrictions on the value of the maximum accelerating field for the biperiodic structure of the linear accelerator of the injection complex of the SILA project", *in Proc 7th Int. Conference Laser, plasma research and technologies (LaPlas-2021)* Moscow, Russia, 23-26 march 2021, pp 414-417. ISBN 978-5-7262-2767-2

[6] S.M. Polozov, V.I. Rashchikov and M.I. Demsky, “Beam dynamics in new 10 MeV high-power electron linac for industrial application”, in *Proc. 25th Russian Particle Accelerator Conference (RuPAC 2016)*, St. Petersburg, Russia, 21 - 25 November 2016, pp. 493–495. doi:10.18429/JACoW-RuPAC2016-WEPSB057

[7] T.V. Bondarenko *et al.*, “New 10 MeV high-power electron linac for industrial application”, in Proc. *7th International Particle Accelerator Conference (IPAC'16)*, BEXCO, Busan, Republic of Korea, 8-13 May 2016, pp. 1794-1796. doi: 10.18429/JACoW-IPAC2016-TUPOW021

[8] D.S. Basyl *et al.*, “Commissioning and first tests of the new standing wave 10 MeV electron accelerator”, in *Proc. 25th Russian Particle Accelerator Conference (RuPAC 2016)*, St. Petersburg, Russia, 21 - 25 November 2016, pp. 173-175. doi: 10.18429/JACoW-RuPAC2016-

[9] CST STUDIO SUITE, https://www.3ds.com/products-services/simulia/products/cst-studio-suite/?utm_source=cst.com&utm_medium=301&utm_campaign=cst